



High Resolution Spectral Mapping of Exo-Zodi Disks with JWST and ALMA for TPF/Darwin

Outline:

- Context
- Zodi properties
- JWST / ALMA

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MPIA Heidelberg
& Darwin TE-SAT

HD to SD to...

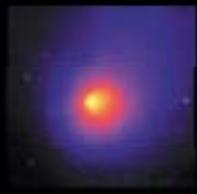


Toward Other Earths:

Darwin / TPF
and the Search for
Extrasolar
Terrestrial Planets

22-25 April 2003
Heidelberg, Germany

DUST DISKS E
and the FORMATION,
EVOLUTION *and* DETECTION
of HABITABLE PLANETS

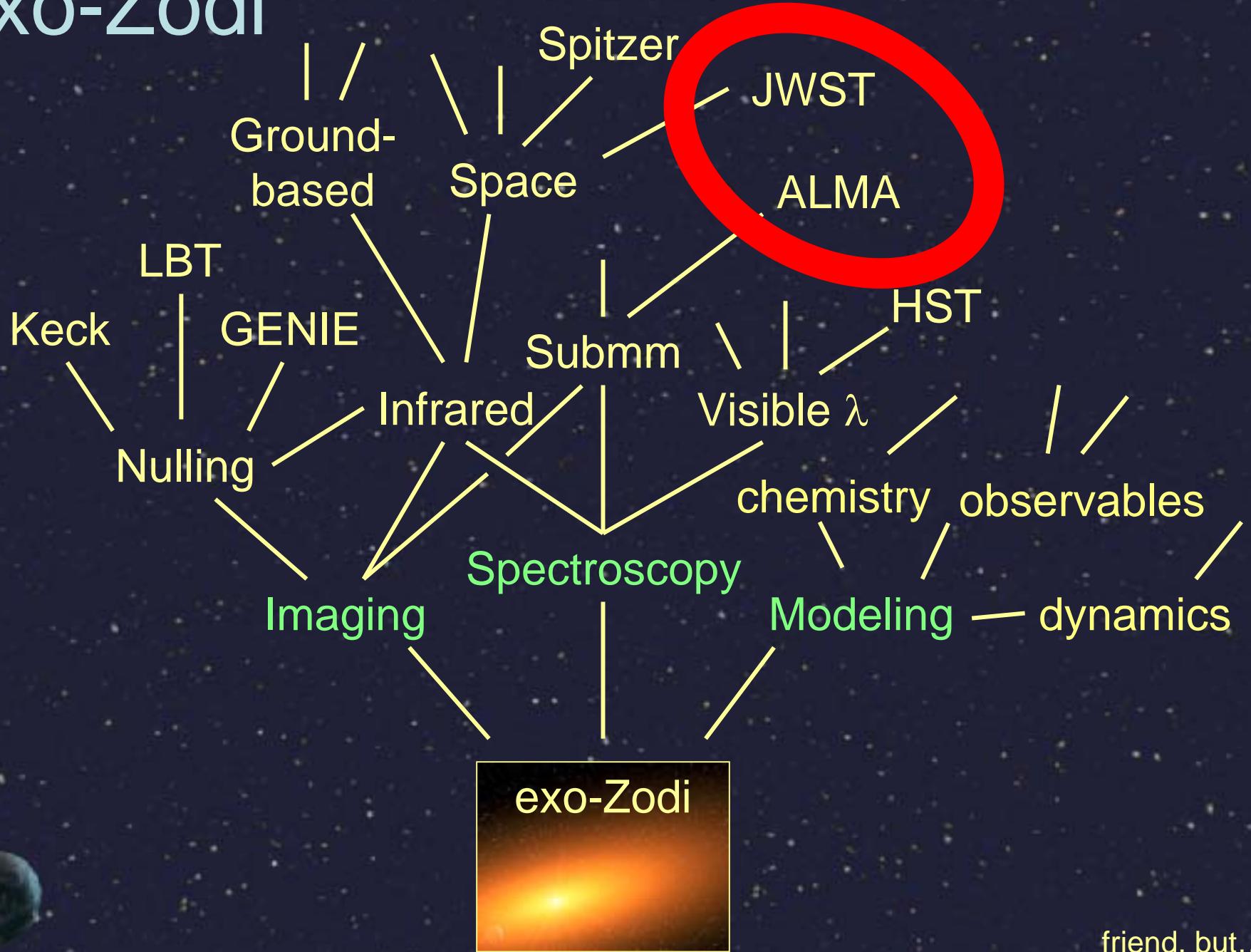


roadmap...

A Roadmap to TPF / Darwin



Exo-Zodi



Exo-Zodiacal Light - friend...

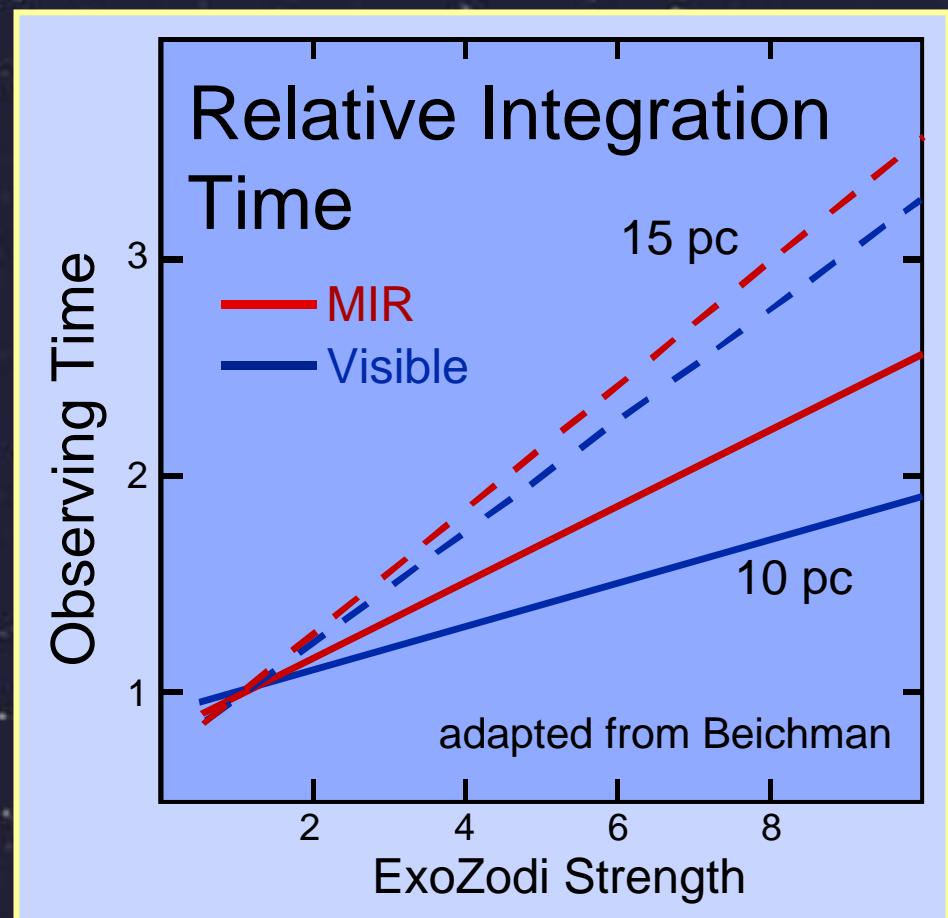
- indicates planetary system (asteroids & comets)

and foe...

- additional noise (C & I)
- dominates for EZ > 10
- structure can confuse



We need to understand



Disk Evolution

Substantial ($0.01 M_{\text{sun}}$)
Gas rich
age few Myr
primordial gas/dust



Low mass ($< M_{\text{earth}}$)
age > 10 Myr
local dust sources

learn...

What we want to learn...

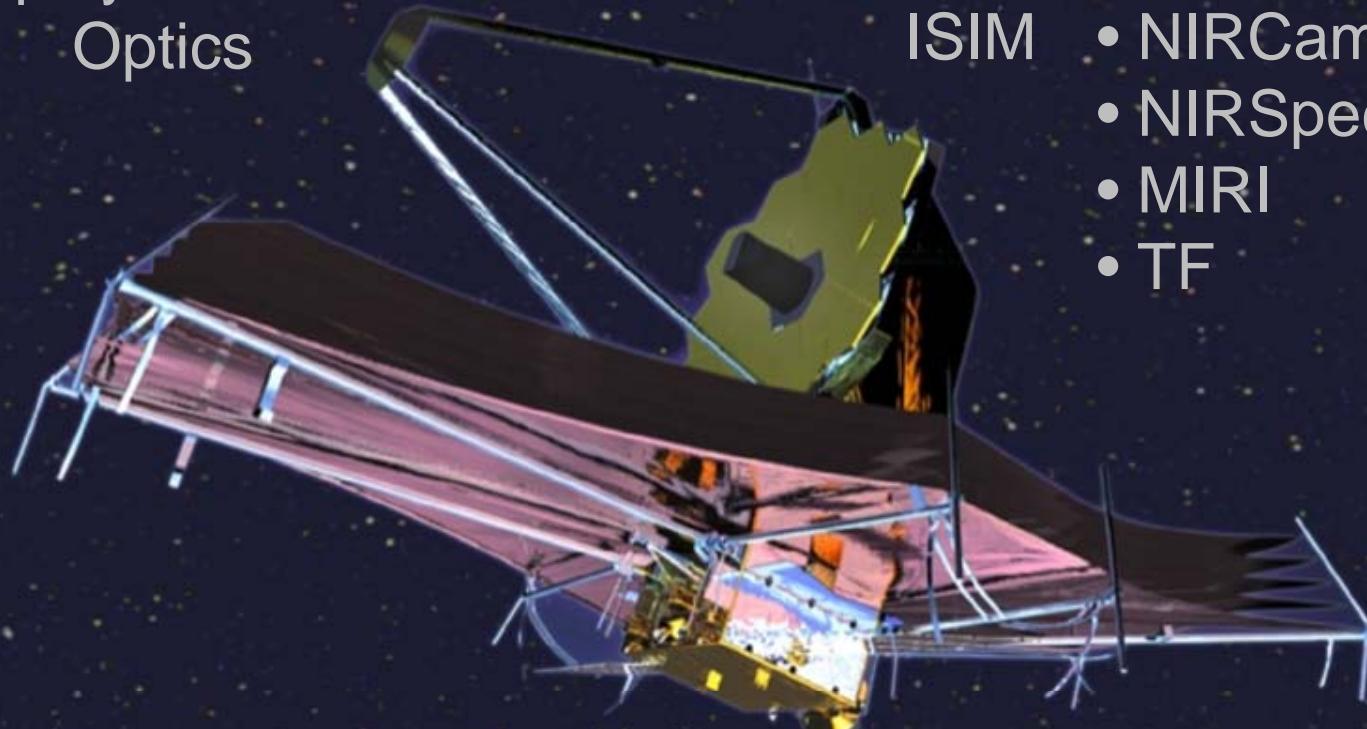
- when and how do the gas and dust dissipate?
 - giant planet formation
 - decoupled?
- when and how does grain growth / processing occur?
- how does the disk structure / composition evolve?
- can disk properties point to the existence of planets?

Not exhaustive, but JWST / ALMA will help



The James Webb Space Telescope

6.5 m
Deployable
Optics



ISIM

- NIRCam
- NIRSpec
- MIRI
- TF

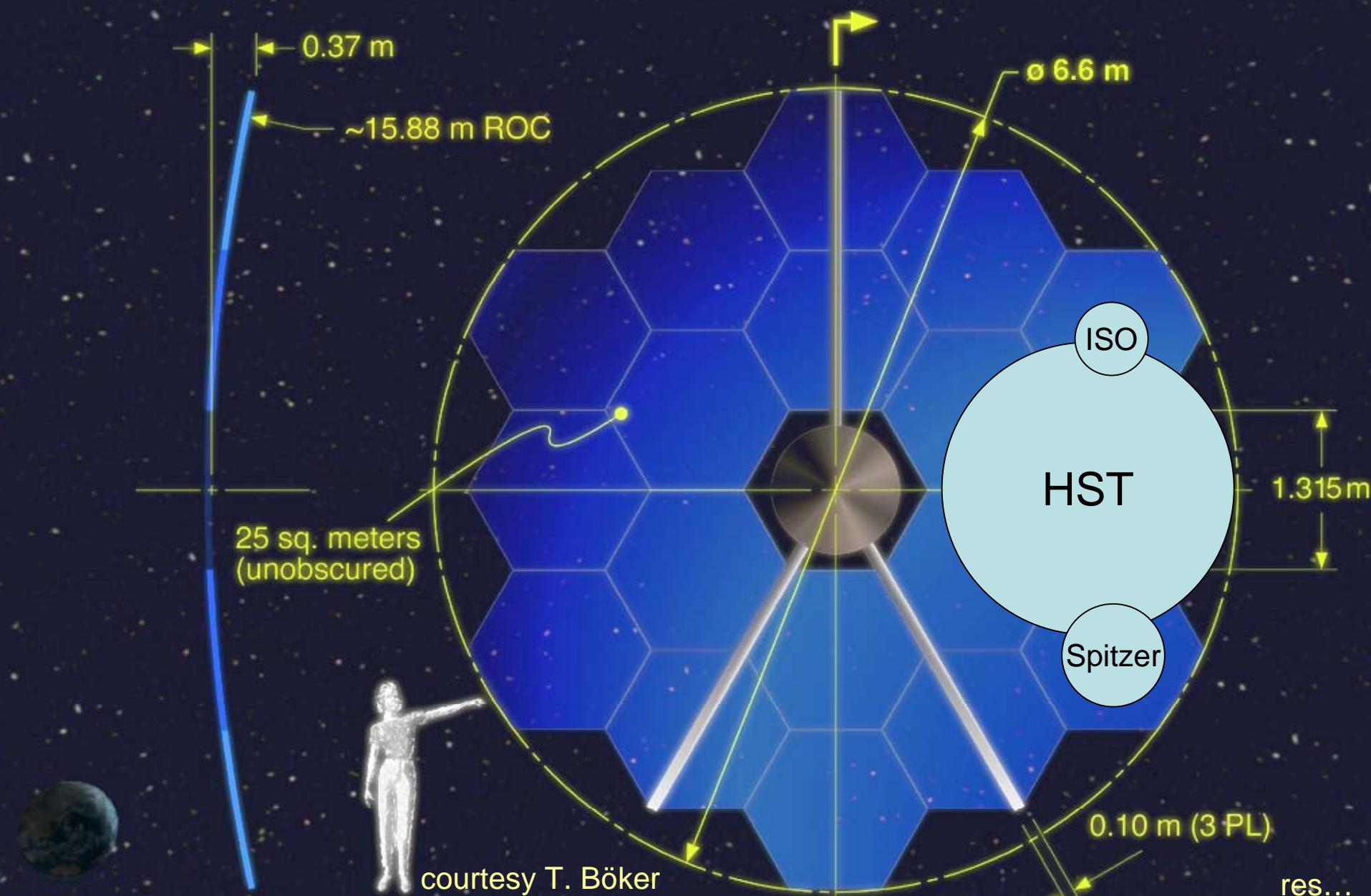
2011 Launch
5 / 10 Year
Mission

Passive Cooling
 $T < 50K$ @ L2



pupil...

JWST Aperture



courtesy T. Böker

res...

Spatial Resolution and Sensitivity

	Diameter (m)	λ/D (arcsec)	Zodi's
Spitzer	0.85	0.7 - 40	~100
JWST	6.5	0.1 - 0.9	~10

Vega:



zodi's, not asteroid / KB

MIRI (most useful)

Imaging

- 5-27 μm , 12 bands
- 1.7 x 1.7 arcmin, BLIP
- R~100, 5-10 μm
- coronagraph (dynamic range)

Spectroscopy

- 5-28 μm , 0.2 arcsec pixels
- R~3000, 5-10 μm ; R~1400 else
- IFU 2x2 arcsec
- coronagraph

Procurement

- optics module - consortium
- detector & cryostat



zodi_sci...

JWST on Exo-Zodi

Caveat: not complete

MIRI Spatially Resolved Imaging and Spectroscopy

- H₂ dissipation in disks
- trace species - nebular chemistry
- solid state features / mineralogy
- ices and molecules in disks (NIRCam / TF)
- organics
- planetary dynamical signatures
- KBO, comet spectra

JWST on Exo-Zodi

Caveat: not complete

MIRI Spatially Resolved Imaging and Spectroscopy

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Molecular Hydrogen

sws - Thi et al. 2001

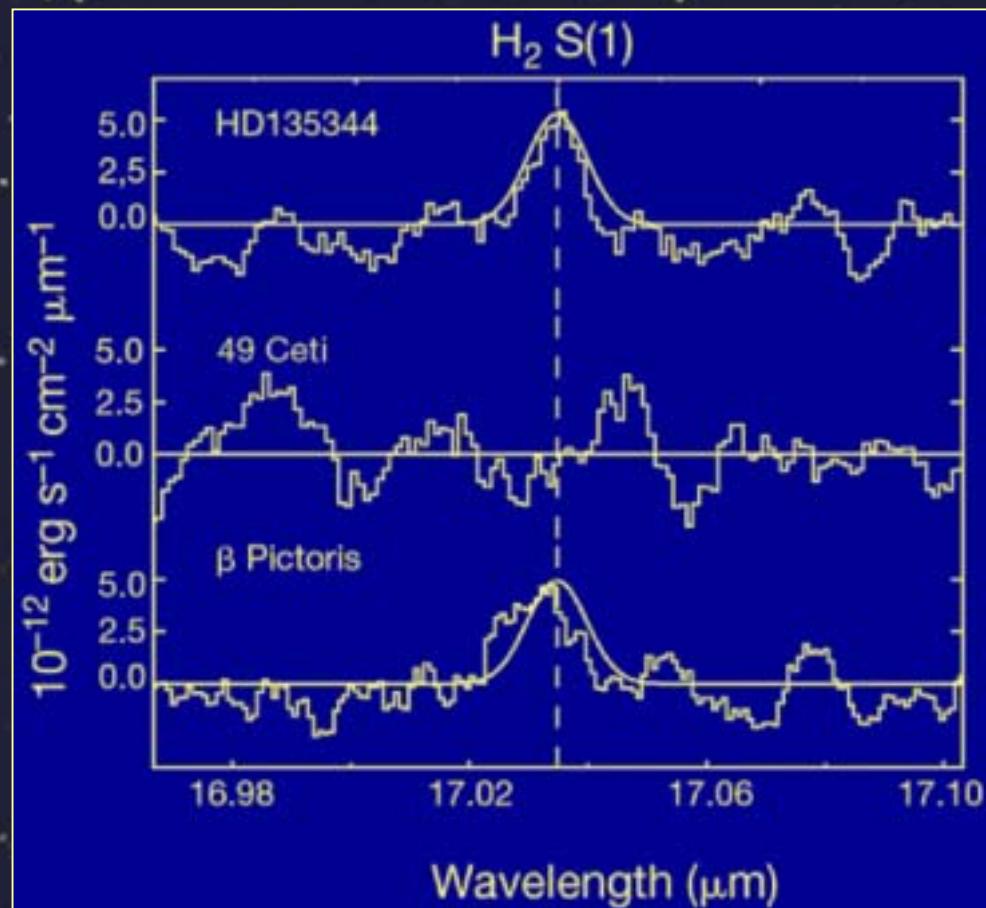
- Traces warm gas
 - 1-50 AU, 50-300K
- Line ratios → $T(r)$ $m(r)$
- with imaging → dust / gas

DRM Survey

- dissipation timescales
- formation of giant planets
- H_2 in dense disks → gaps?

JWST

- spatial resolution, sensitivity
 - contamination, spectral R?
- best ages in clusters
 - few and far



MIRI Rotational H_2 Lines

$S(3)$ 9.66 μm	$S(1)$ 17.03 μm
$S(2)$ 12.28 μm	$S(0)$ 28.22 μm

Disk Mineralogy

- dust composition / processing
- silicate features, PAH, ices
- chemical evolution of dust

Zodi Disk Evolution

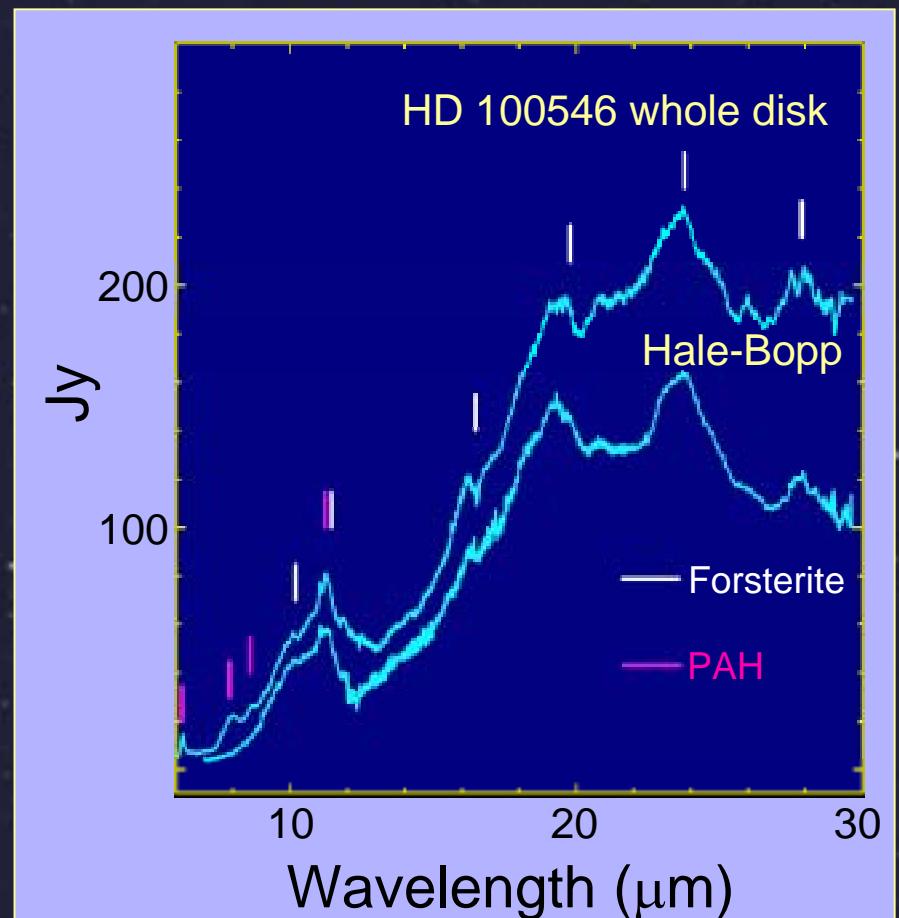
- Xtal Silicate feature → hot
- but seen in comets:
 - ejection by planets?

Particle size diagnostics

- depth vs size - size matters
- inversion of Xtal Si feature (Min)
- can we see this?

JWST

- sensitivity, spatial resolution
- spectral mapping



SWS - Malfait et al. 1998

MIRI Astromineralogy

Silicate 9.7, 18 μm
 Mg_2SiO_4 10, 11, 17, 20, 24, 28 μm
FeO 23 μm

organics...

Organics

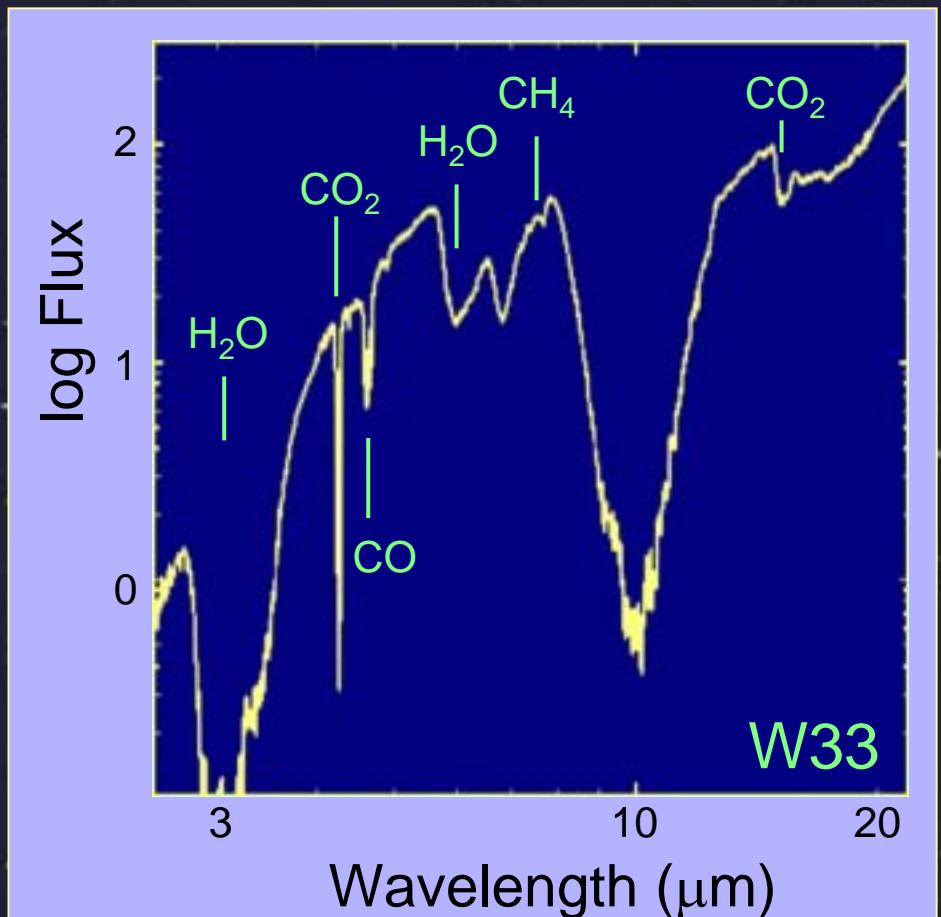
- transport of life elements
- C,N,O to biogenic molecules
 - H_2O , CH_3OH , CO, CO_2 , H_2
 - PAH (carbon), NH_3 abundance
 - e.g. $\text{NH}_3 + \text{H}_2\text{CO} \rightarrow$ amino acids
- biogenic from cloud to planet
 - N.B. organic ices on comets, outer planets, KBO's

DRM Study

- abundance (t,r) of organics
- formation / modification

JWST

- sensitivity, telluric H_2O , CO_2
 - spatial res'n, spectral mapping

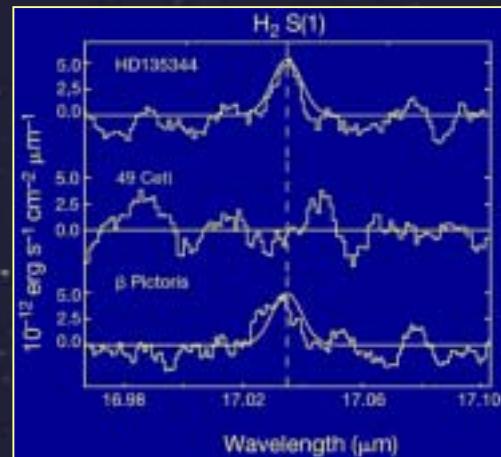


SWS - Gibb et al. 1999

JWST Ices

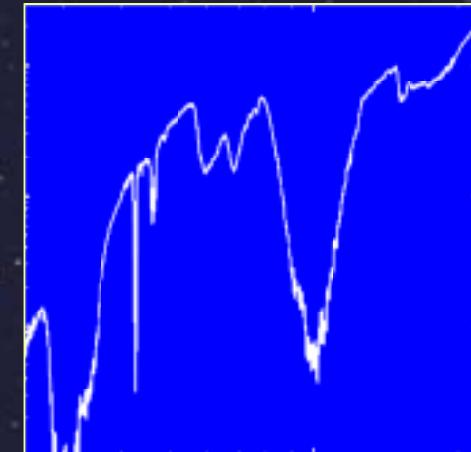
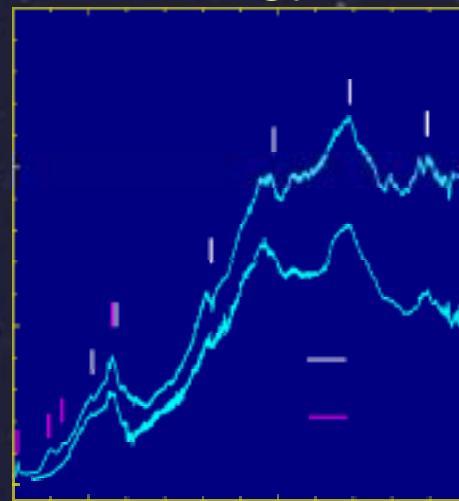
H_2O	3, 6 μm
CO, CO_2	4.3, 4.7, 15 μm
CH_4	7.6 μm

Mapping (not SWS spectra)



H_2

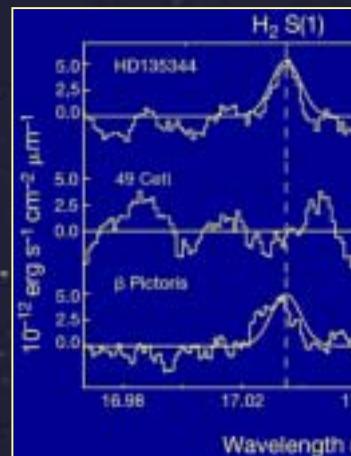
Mineralogy



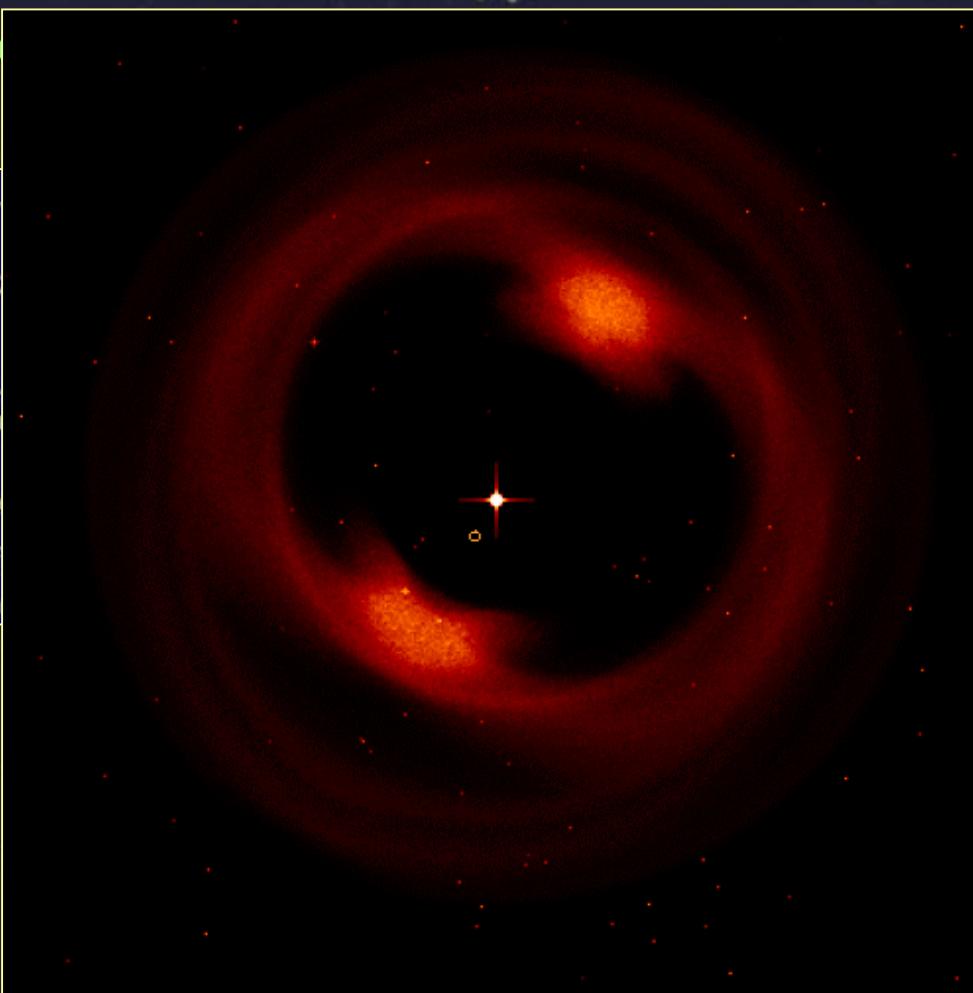
Organics

Mapping

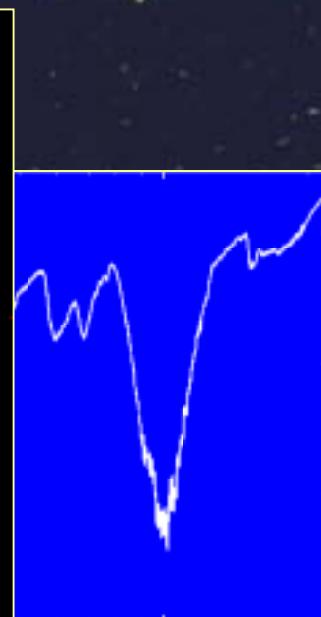
(not SWS spe)



H₂



M. Kuchner



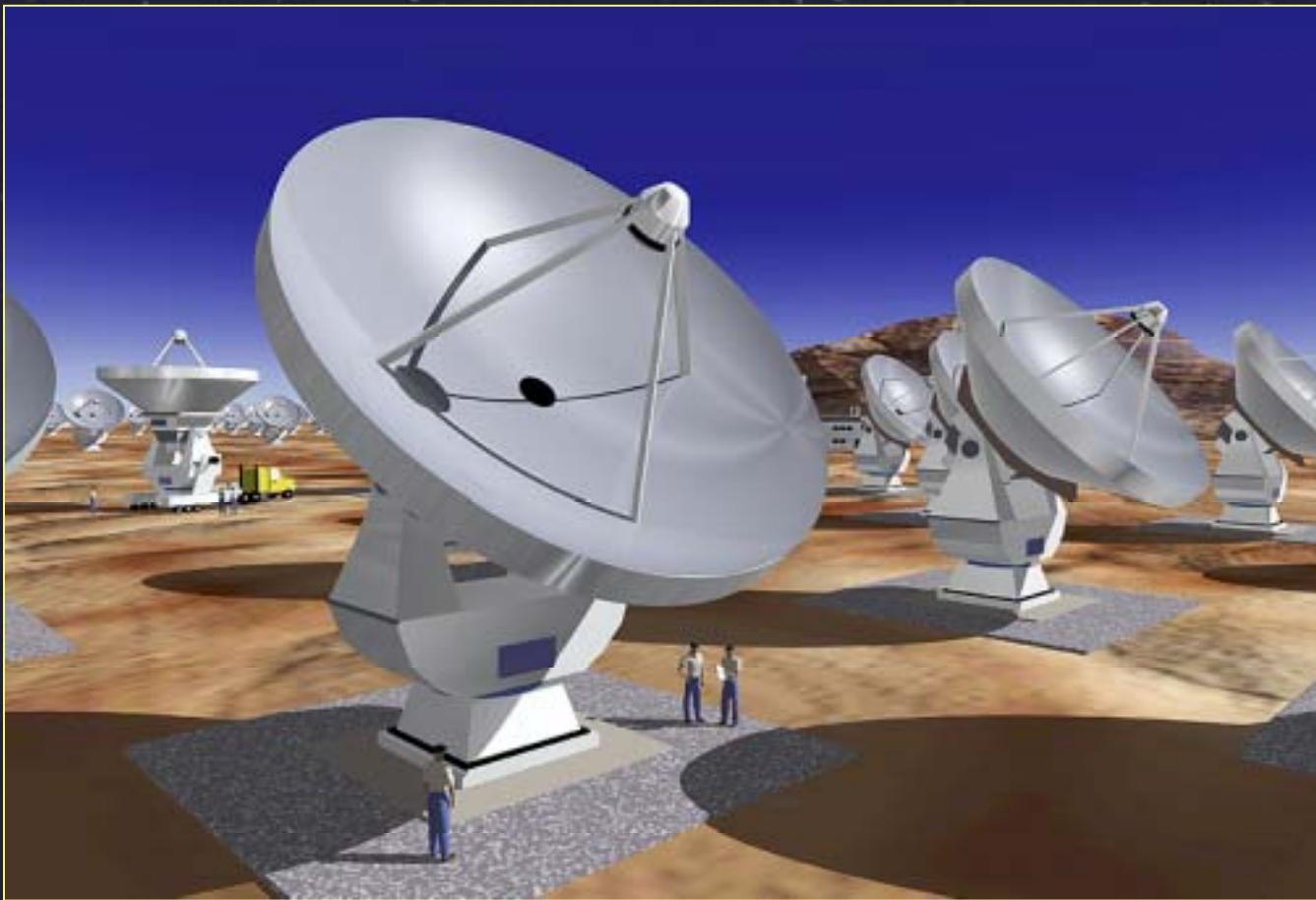
nics

(spatial and temporal at AU scales)

ALMA...

ALMA

Atacama Large Millimeter Array

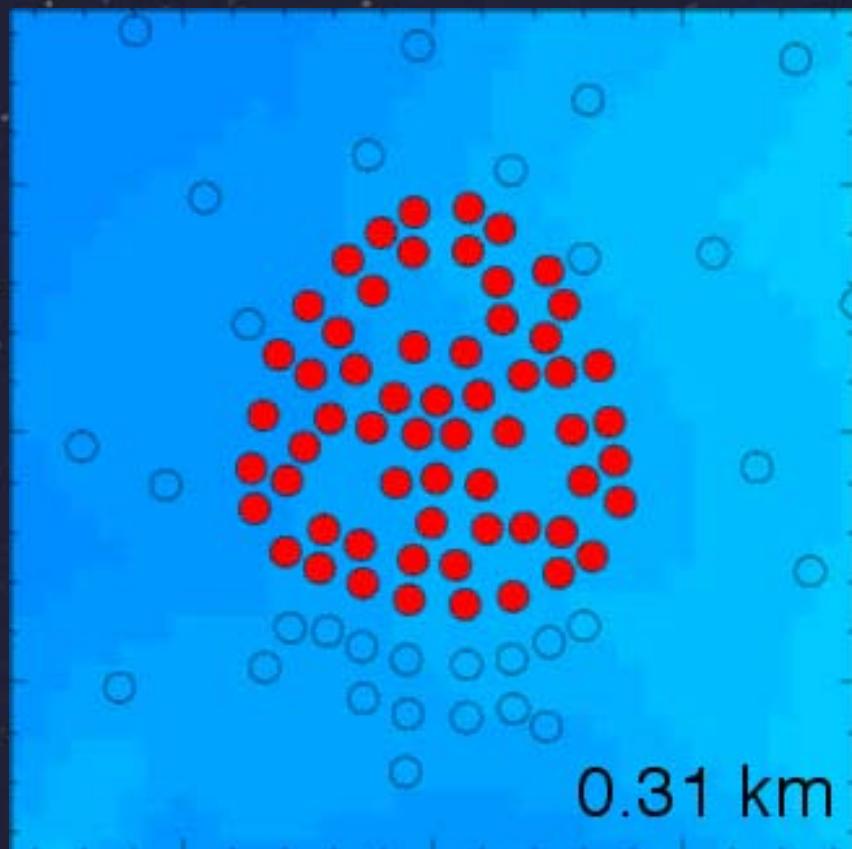


- 64 dishes
- 12 m dia.
- 25 μm RMS
- 0.3 - 7 mm

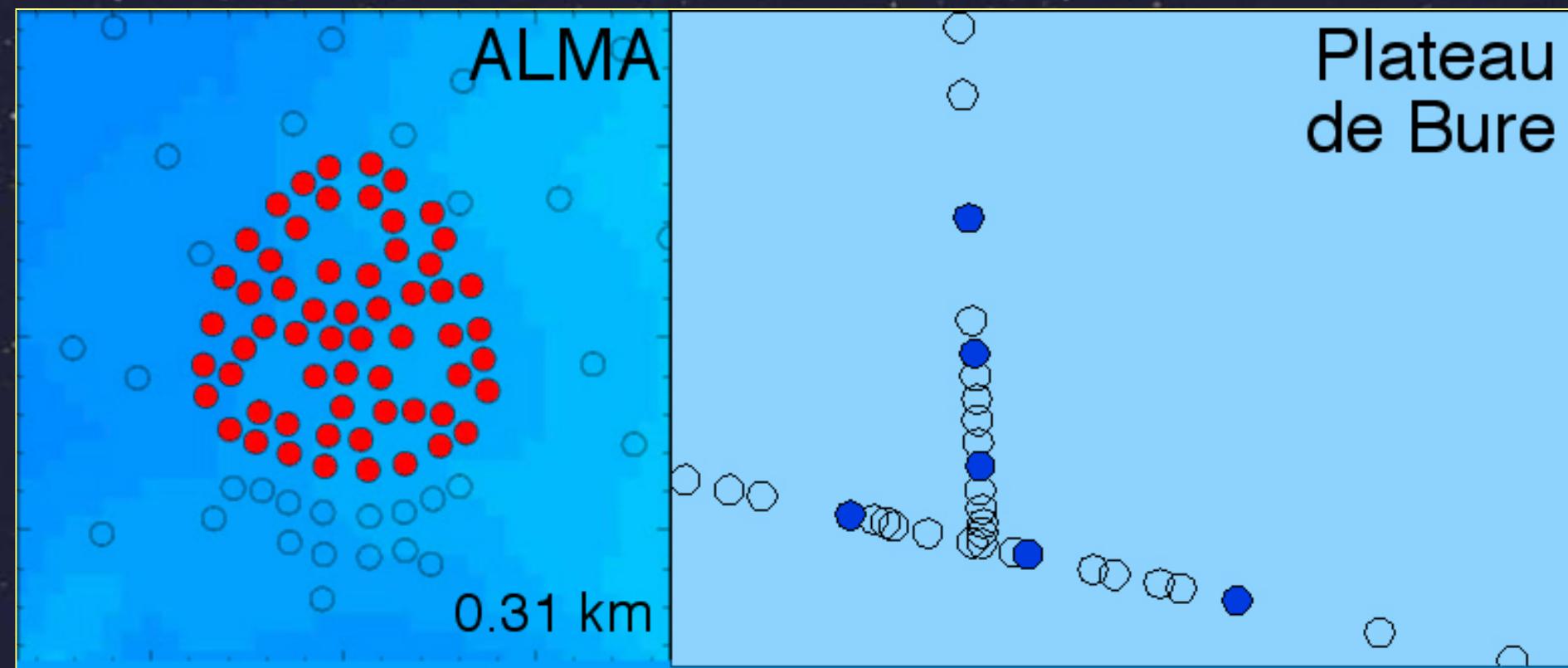
pupil...

ALMA Aperture

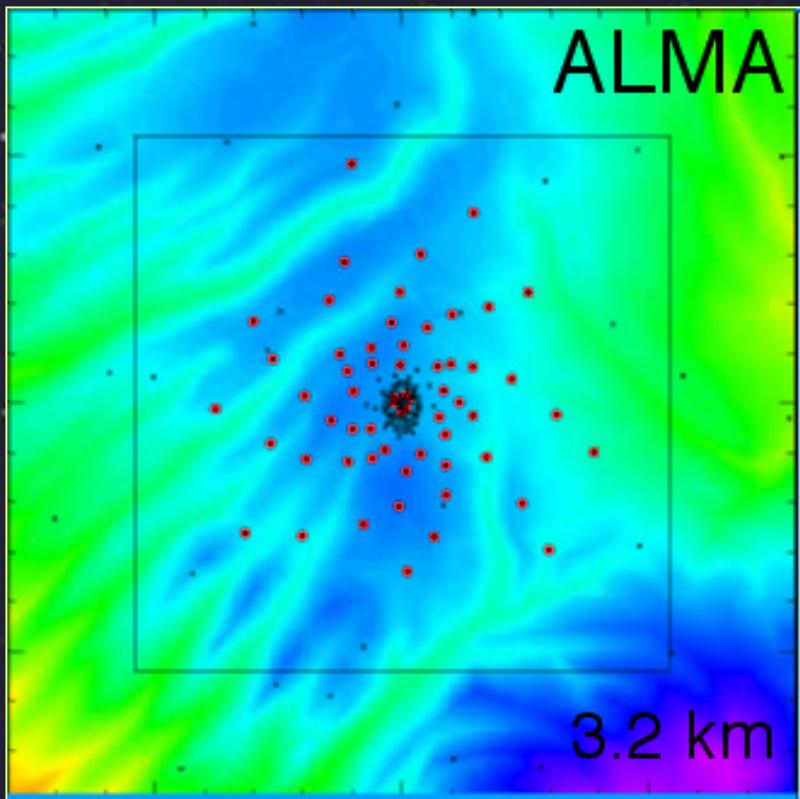
- 2016 baselines → images
- continuous reconfiguration
- 0.15 - 14 km baselines
- 2 compact for sensitivity
- largest: distorted Y



ALMA Aperture

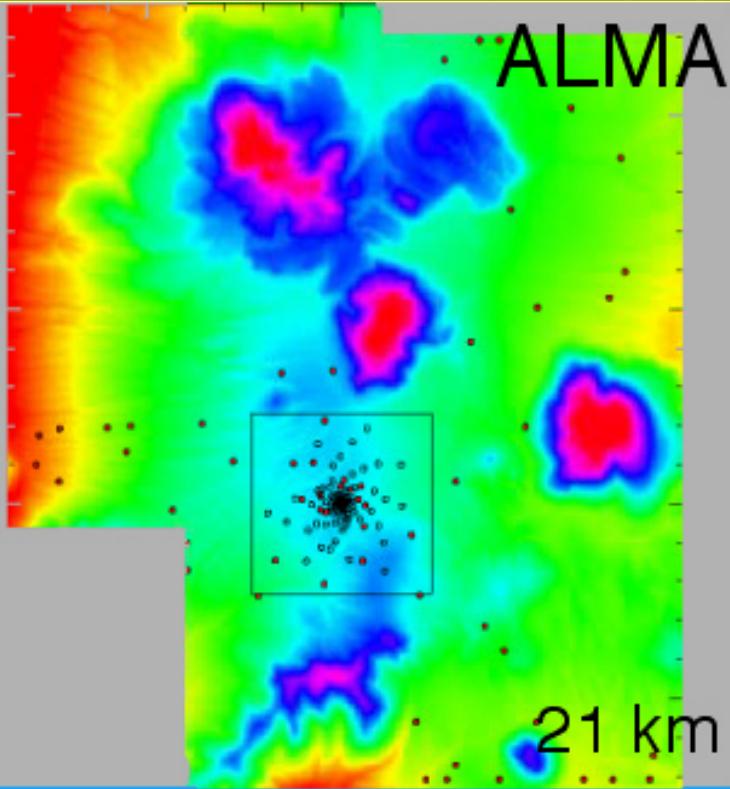


ALMA Aperture



Plateau
de Bure

ALMA Aperture



Plateau
de Bure

ALMA Aperture



- Chajnantor, Chile 5000 m
- First dish science 2007
- Full array 2011

Dust Imaging

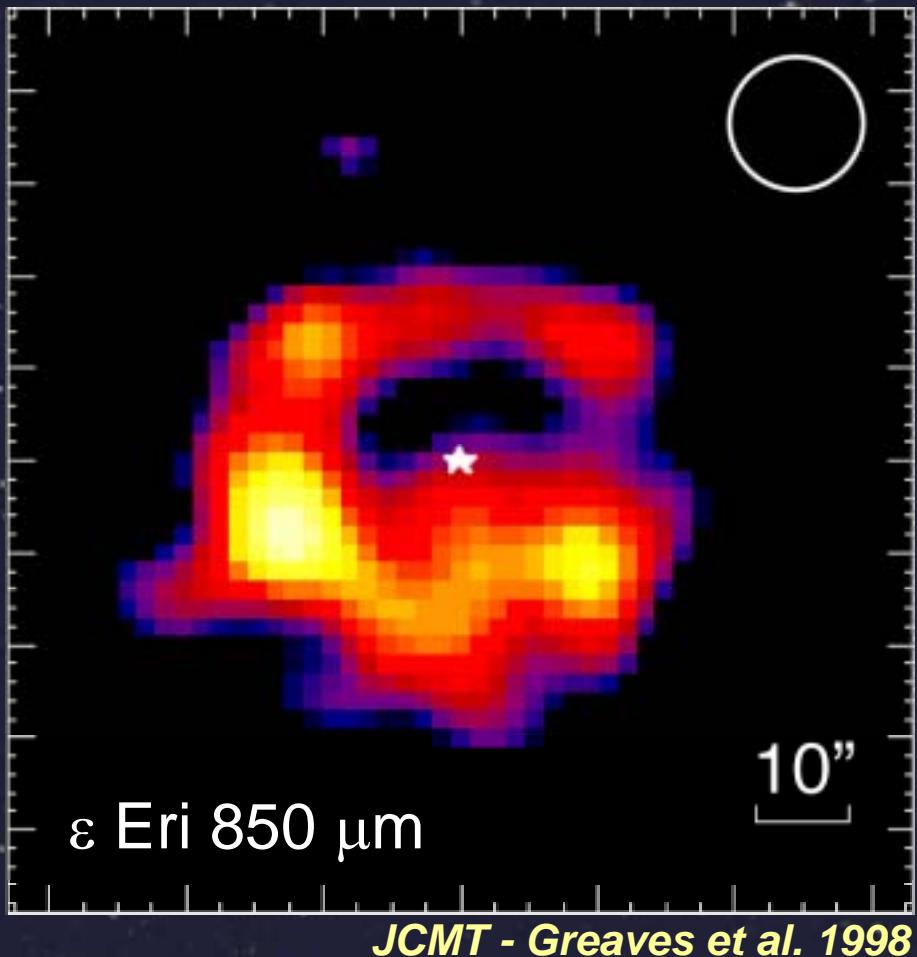
- cold (10-100K) dust to 100 AU
- subarcsecond resolution

ALMA Survey Program

- disks 5-100 Myr
- cold dust distribution
 - search for KB dust equiv.
- environment effects
 - photo evaporation, tidal
- planet effects ?

ALMA

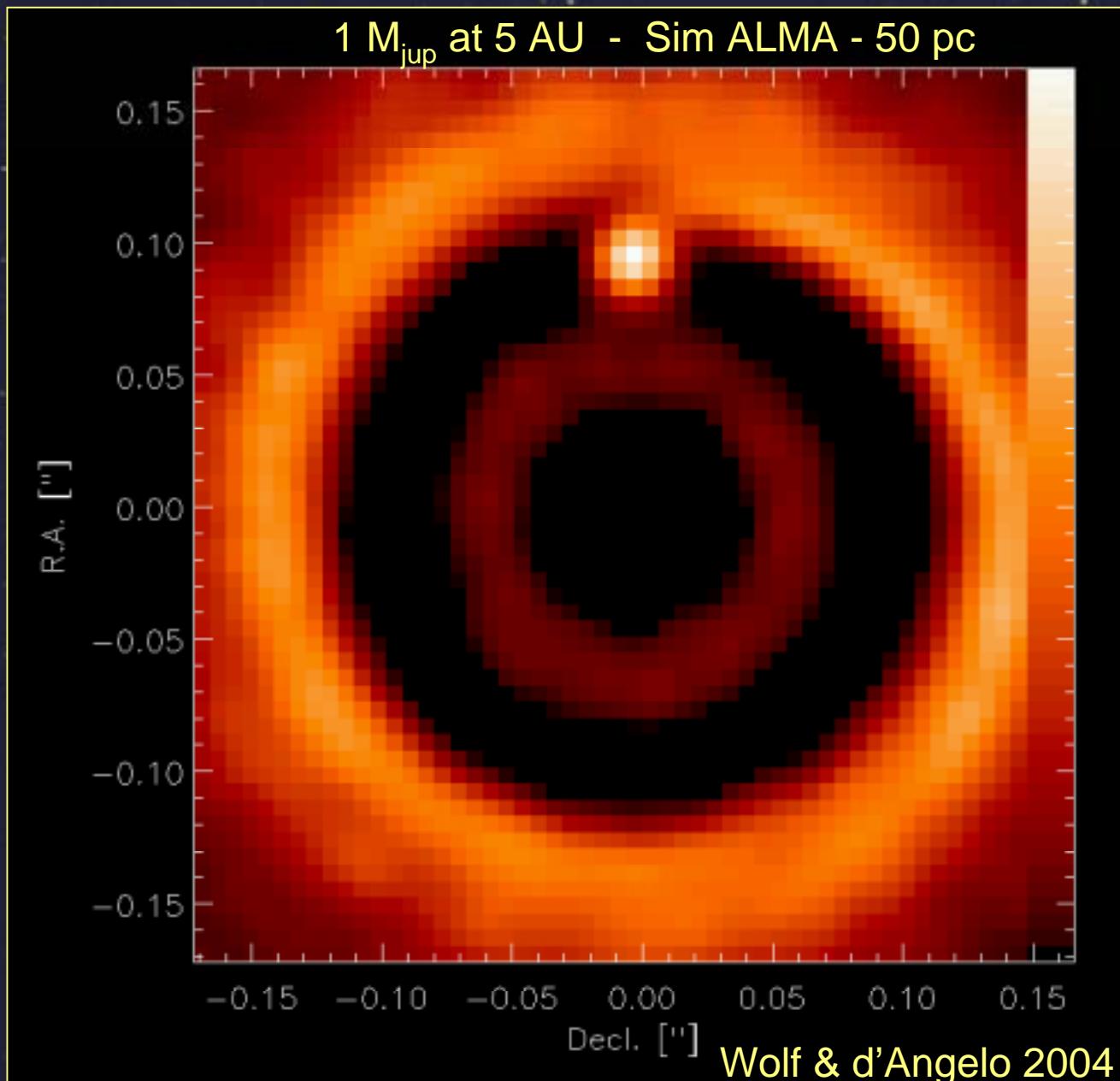
- sensitivity
 - $0.01 M_{\text{Earth}}$ to 100 pc
- 10x spatial resolution, sensitivity



ALMA Dust

Dust 0.3 - 7 mm

Dust Imaging

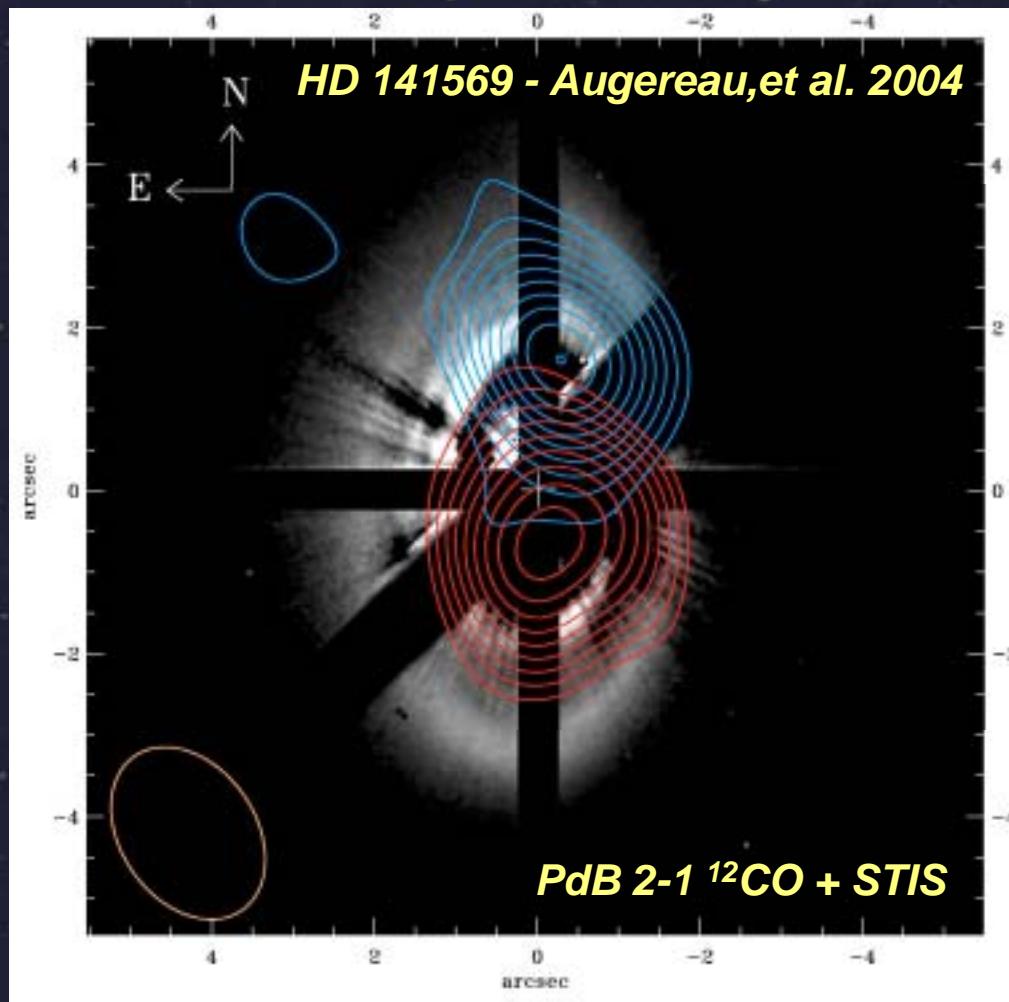


Gas Mapping

- CO, HCO⁺, H₂D⁺, N₂H⁺
- spatial distribution

ALMA Program

- dispersal with age
 - gas / dust ratio (t)
 - distribution → origin
 - cometary rings?
 - uniform ?



ALMA

- sensitivity
 - impossible without ALMA

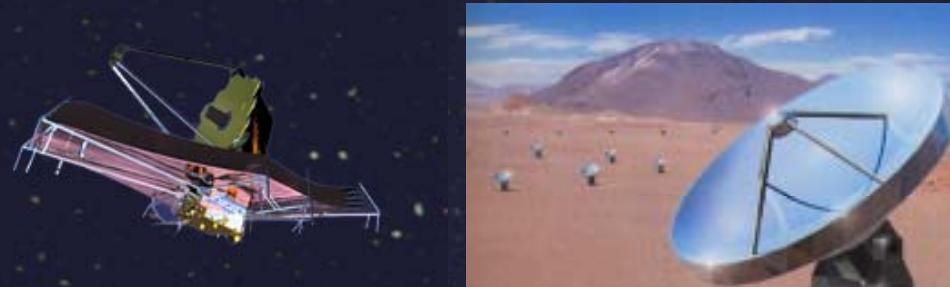
ALMA CO

CO 2-1 1.35 mm

CO 1-0 2.7 mm

combined...

Combined Approach

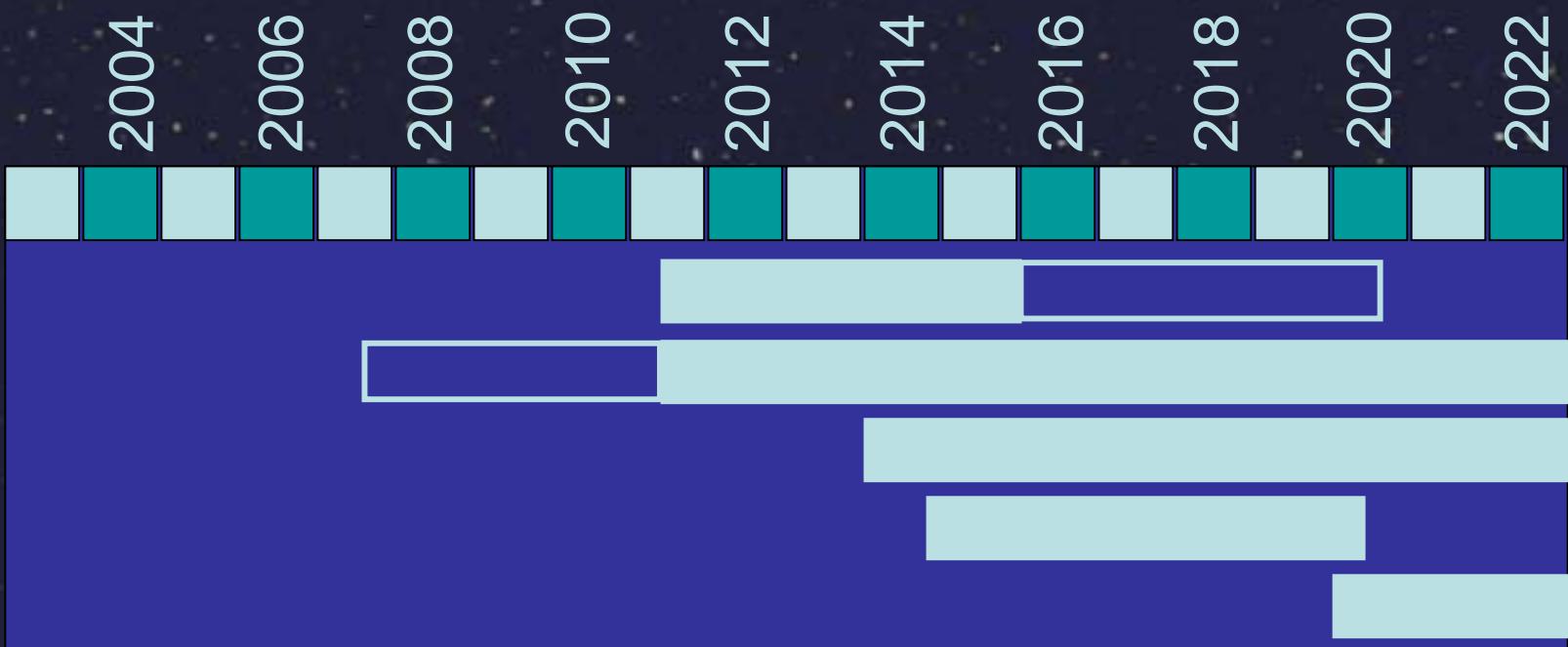


Wavelength
Spatial Resolution
Spectral Resolution
dust
spectroscopy

0.6-28 μm	0.3 - 7 mm
0.1 - 0.9	0.015 - few
few - 3000	10^6
warm, small	cold, large
60-1000K	10-100 K
gas (H_2), solid state, PAHs, organics	gas phase molecules, CO

when...

When



to learn more...

To Learn More...

Web Sites

<http://ngst.nasa.gov>

<http://ircamera.as.arizona.edu/MIRI/>

<http://www.alma.nrao.edu/>

<http://www.eso.org/projects/alma/>

2015

Ringberg...

Ringberg Workshop on Planet Formation: Theory meets Observation.



SOC:

D. Fischer

L. Hillenbrand

C. Terquem

P. Artymovicz

W. Benz

P. Bodenheimer

A. Boss

A. Burkert

Th. Henning

D. Lin

M. Mayor

M. Rozyczka

S. Weidenschilling

Dec. 19th-22nd 2004

<http://www.mpia.de/Planets2004>



Question 1: What are the observational constraints on planet formation theory?

Question 2: What observables can be derived from theory for future observations?

Organizer: H. Klahr & W. Brandner
Max-Planck-Institute for Astronomy